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Watershed Best Management Practices for Water Quality Protection, Management, and Restoration

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PURPOSE: This technical note describes the need for and use of a variety of best management practices (BMPs) for urban and agricultural watersheds as a means to manage, protect, and restore the quality of water resources.

BACKGROUND: Sediment, organic material, and nutrients transported from watersheds to rivers, lakes and reservoirs, and coastal zones are a primary cause of water quality degradation (Figure 1). While the transport of these materials from watersheds to water resources is a natural process referred to as eutrophication, excessive inputs (or loading) of sediment, oxygen-demanding organic material, and nutrients can lead to increased suspended matter concentrations, nuisance algal blooms, proliferation of aquatic weeds and reduced dissolved oxygen concentrations in bottom waters. These responses can lead, in turn, to anoxia, reduced water clarity and aesthetics, lost habitat value, taste and odor problems for drinking water supplies, potential threats to human and livestock health (e.g., due to blooms of toxic algae), decreased volume due to sedimentation, and lost user benefits.

Since many sources of nutrients, sediment, and organic materials are diffuse and widely distributed (and, therefore, often referred to as non-point sources), control is difficult. Examples of non-point sources include cropland, animal feedlots and grazing lands, impervious surfaces (e.g., rooftops, parking lots, and roads), and construction sites. In general, agricultural and urban land uses lead to increased rates of runoff and erosion. Because of this, rates of material export from watersheds to water resources, while highly variable within and between land uses (Beaulac and Reckhow 1982), exceed those for natural or undisturbed land uses (see, for example, Table 1).

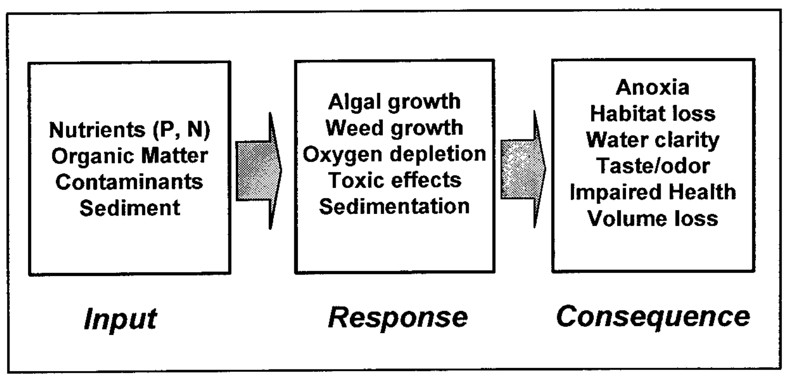

Figure 1. Linkages between the export of material from watersheds, water quality responses in receiving waters, and the consequences of such responses

The application of fertilizers, including the spreading of manure, and the disruption of soil surfaces by tilling increases the rate of nutrient and material losses from croplands. Inorganic fertilizers and manure, when applied at rates exceeding the assimilative capacity of crops and soils, greatly increase the amount of growth-stimulating nutrients entering receiving waters. Soil preparation for planting and the lack of vegetation cover during the non-growing season, as well as the loss of vegetative

Table 1
Average Total Phosphorus Concentrations in Stormwater Runoff from Various Land-Use Practices[1]

Land Use	Phosphorus Concentration, mgP/l
Residential	1.0
Commercial	1.08
Agriculture	0.451
Animal feed lot	85.0
Forest	0.015

[1] Based on values reported in Cooke and Kennedy (2001).

cover due to overgrazing or poor pasture management practices can increase erosion and the export of nutrients from agricultural watersheds.

Accumulated materials (e.g., domestic animal feces, leaves and other organic debris, oil and grease) washed from impervious surfaces during storm events, particularly in urban areas, result in high material loads to receiving streams or lakes. In many cases, such loads exceed those associated with such point sources as treated domestic sewage or industrial waste. The collection and routing of storm water through gutters, curbs, and storm drains exacerbates pollution impacts by delivering runoff water to streams and lakes with minimal time for infiltration and material retention.

MANAGING MATERIAL INPUTS: Despite the fact that point sources of pollution (e.g., sediments, organic matter, and nutrients, such as nitrogen and phosphorus) have been the target of control measures implemented since enactment of the Clean Water Act of 1972, the recently published National Water Quality Inventory (U.S. Environmental Protection Agency 1996) indicates that over 40 percent of the nation's fresh waters remain impaired and do not meet water quality standards for their designated use. In response to this, the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency 1999) has established the Total Maximum Daily Load (TMDL) Program as a means to more effectively control or reduce the total quantity of materials exported from watersheds to water resources.

The TMDL process is initiated when a body of water is identified as not meeting water standards. Once identified as exhibiting impaired water quality, the TMDL process requires that the source(s) of impairment be identified and that the loads of materials resulting in the impaired condition be reduced to a level that restores the water quality. In general, the sum of material loads to the water body, from both point and non-point sources, is compared to the allowable load using a simple mass-balance equation:

$$\mathrm{TMDL} = \mathrm{LC} = \Sigma \mathrm{PS} + \Sigma \mathrm{NPS} + \mathrm{MOS}$$

where:

TMDL = Total Daily Maximum Load
LC = Loading capacity
PS = Point source pollutant load
NPS = Non-point source load
MOS = Margin of safety

The TMDL process allows watershed partners to assess current conditions, anticipate future management requirements, and to design and implement ameliorative strategies. Martin and

Kennedy (2000) provide an overview of the TMDL process and how it relates to Corps of Engineers projects and missions.

BEST MANAGEMENT PRACTICES: The significance of non-point source loading is well established. Novotny and Chester (1981) reported that prior to 1980, nearly half of the sediment loads to streams and rivers were attributed to export from agricultural lands, and that non-point sources accounted for 80 percent and 50 percent, respectively, of nitrogen and phosphorus loads to receiving waters. Non-point sources also contributed nearly 98 percent of the total load of fecal coliform bacteria. While improvements in the treatment of point sources have greatly reduced their impacts to receiving waters over the last 20 years, non-point sources continue to have a significant impact on the quality of water resources (U.S. Geological Survey 1999).

Effective control or reduction of non-point source loads will require implementation of best management practices or BMPs in the watershed. BMPs may involve efforts to change land-use practices or watershed activities in ways that reduce material exports, or the construction and operation of features that retain materials or reduce the rate at which they are transported from the watershed. The type of BMP implemented will reflect local conditions (e.g., geology and soils, topography, climate, and hydrology), societal expectations, and the nature of the source of the polluting material (e.g., specific urban, residential, or agricultural land uses).

Urban BMPs. Imperviousness is a major determinant in non-point source loading from urban and residential areas. Development (e.g., construction of homes and commercial or industrial buildings) and construction of roads and parking lots increases the degree of imperviousness in a watershed. The relationship between degree of imperviousness and runoff (often expressed as a runoff coefficient or the fraction of precipitation that runs off a site) is well-established. Schuler and Holland (2000) report that the volume of runoff from a 1-ha paved parking lot (runoff coefficient of 0.95) is 16 times greater than the runoff volume from an undeveloped meadow (runoff coefficient of 0.06).

In addition to reducing infiltration of precipitation, impervious surfaces accumulate materials, including soil and grit, organic waste, nutrients, oil and grease, and contaminants, that are washed to streams and storm sewers during runoff events. Schuler and Holland (2000) compared the quantity of nutrients exported from a parking lot and meadow having similar dimensions and slope, and determined that annual nitrogen and phosphorus exports were 7 and 4 times higher, respectively, for the parking lot. Clearly, impervious surfaces can greatly increase material loads to water resources.

BMPs for urban and residential watersheds follow two strategies: reducing or preventing runoff and resultant pollutant loading, and treating runoff water. Limiting the amount of impervious surface is a prime consideration for reducing runoff and the resulting loss of pollutants. This often involves the inclusion of infiltration features (infiltration trenches or basins) in landscape designs, limitations in the use of curbs on streets and driveways, and parking lot designs that include pervious, vegetated areas (see, for example, Figure 2). Additional considerations include 'housekeeping' or the routine removal of debris accumulating on roads, driveways and parking areas, regulations on leaf management and domestic animal waste, and sound landscaping maintenance.

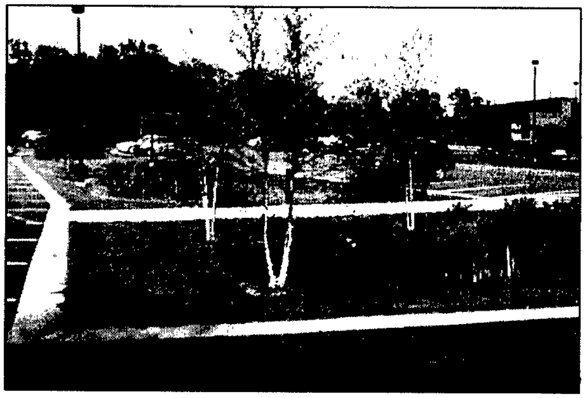

Figure 2. Parking lot designs that limit curbing and incorporate pervious infiltration areas reduce storm water runoff volume and the export of materials to nearby streams

Collecting or controlling runoff offers the opportunity to treat storm waters before they are introduced to water resources. Retaining water in permanent or temporary ponds or retention basins allows for material losses due to increased sedimentation, as well as reduced erosion rates, increased infiltration, and reduced rates of water delivery to receiving streams and wetlands. The creation of wetlands (Figure 3) or the management of existing wetland features, including vegetated riparian strips along water courses or vegetated infiltration features, can greatly reduce runoff rates while retaining significant quantities of nutrients and sediments.

Commonly employed BMPs for urban and residential watersheds are listed and briefly described in Table 2.

Figure 3. Constructed wetlands and retention ponds, like these in an urban residential area near the Minneapolis Chain of Lakes, MN, can markedly reduce nutrient loading to nearby lakes while providing habitat and aesthetic value

Agricultural BMPs. Runoff from agricultural lands and the attendant loss of sediment, nutrients, and pesticides are significant sources of water quality degradation. Brach (1991) reports that non-point sources account for 73 percent of the sources of the nutrients and sediments entering Minnesota's degraded lakes and rivers. Similarly high percentages are reported for non-point source impacts in other agricultural regions. These impacts are related to the use of nutrient amendments (including inorganic fertilizers and manure), manipulation and disruption of soil surfaces for crop production, and livestock operations, all of which can greatly increase the rates of water, sediment, nutrient, and organic matter losses to water resources (e.g., Figure 4).

Commonly employed BMPs for agricultural watersheds involve modifications to farm and resource management practices, changes in vegetative and tillage practices, and the use of structures to retain or otherwise control the movement of water and material (Table 3). The key element of each is reduced sediment and nutrient losses by limiting erosion or wash-off. For instance, planned scheduling (i.e., the timing and quantity of water or material added) of the application of nutrients, either as inorganic additives or livestock manures, and irrigation water to agricultural lands can greatly reduce the amount of 'excess' water and material that is lost from the application site by leaching or runoff.

Table 2
Common Best Management Practices (BMPs) for Controlling Sediment and Nutrient Exports from Urban Watersheds

Practice or Application	Description
Runoff Pollution Prevention	
Impervious surface reduction	Reducing the amount of impervious surface, particularly driveways and parking areas, promotes infiltration and reduces runoff volumes and associated losses of nutrients.
Housekeeping	Included are routine removal of street debris (i.e., street sweeping), management of animal (both domestic and wild) wastes, improved landscape maintenance, and structures (e.g., grit chambers) to retain coarse materials (sand and grit).
Construction practices	Protection of temporarily disturbed surfaces by appropriate grading practices, sequenced construction activities, and vehicle track maintenance (e.g., use of pads of solid or aggregate material).
Soil erosion control	Maintenance of vegetative cover and the use of mulch or geotextiles to reduce loss of soils and associated nutrients and organic material.
Sediment control	Use of structural barriers (e.g., check dams and berms) and silt curtains to trap and retain suspended material.
Storm Water Treatment	
Retention systems	Ponds or subterranean chambers (e.g., vaults and oversized pipes) to temporarily retain stormwater runoff. Sediments and nutrients are removed due to increased rates of sedimentation.
Detention systems	Dry ponds and swales slow stormwater runoff, reducing erosion and soil loss. Retained water is subsequently released or allowed to infiltrate.
Flow control structures	Flow rates or the distribution of storm runoff are controlled through the use of permeable weirs and flow splitters.
Infiltration systems	Vegetated basins and trenches, or onsite landscape areas allow increased infiltration of runoff water and the retention of nutrients and sediment.
Constructed wetlands	Creation (using dams or modifying drainages) of wetlands offers the means to retain sediment and dissolved nutrients, while providing wildlife habitat and aesthetic value. Wetlands can often be incorporated into community landscape improvement efforts.
Filtration systems	Includes a variety of vegetated (e.g., grassed filter strips), mechanical (e.g, sand filter chambers and underground filter cascades), and landscape design approaches for removing materials from runoff water.

Changes in tillage practices are designed to protect soil surfaces, particularly during periods of minimal plant coverage, as a means to reduce soil loss due to erosion. Conservation tillage and strip cropping limit the amount of surface tilled, while contour tillage orients tilling and planting along topographic contours to reduce erosion. Contour tilling can reduce soil loss due to erosion by as much as 50 percent (Brach 1991). Strips of close-growing plants or alternating crop types within the same field can also reduce material losses due to erosion.

Figure 4. Poor land management practices can greatly increase material (nutrients and sediments) transport to water resources

Table 3
Common Best Management Practices (BMPs) for Controlling Sediment and Nutrient Exports from Agricultural Watersheds. Based on Brach (1991)

Practice or Application	Description
Management Practices	
Nutrient management	Careful management of soil fertility through scheduled application of fertilizer and animal waste (manure) to ensure proper rates of fertilization and minimize losses.
Irrigation water management	Controlling the rate, timing, and amount of irrigation water to reduce soil erosion and leaching of nutrients.
Vegetative and Tillage Practices	
Conservation tillage	Tillage designed to leave at least 30% of the soil surface covered with crop residue as a means to protect soil losses due to erosion by wind and water.
Contour farming	Tillage and planting of crops along topographic contours to reduce erosion and increase infiltration. Can reduce erosion by as much as 50%.
Stripcropping	Use of alternating strips or contours of various row crops, sod, or close-growing crops.
Filter strips and field borders	Use of strips of grass or other close-growing vegetation to reduce transport of sediment and associated nutrients. Normally planted in areas experiencing sheet flow.
Cover crop and rotation	Planting of close-growing grasses, legumes, or small grains to protect and improve soil, and periodic changes in crop type. Residues to cover crops provide green manure and reduce fertilizer needs.
Pasture management and windbreaks	Proper use of pastures to ensure maintenance of foliage, and the use of trees or shrubs at field edges to reduce sediment losses due to wind and water erosion.
Structural Practices	
Waste-handling facilities	Use of waste storage ponds, structures, and confined areas to temporarily retain manure and other agricultural wastes at feedlots, animal containment areas, and barnyards. Facilities must be properly designed to prevent seepage and groundwater contamination. Such facilities can be highly effective in reducing the export of nutrients and oxygen-demanding materials to surface waters.
Water and sediment control structures	Construction of settling basins, earthen embankments, and diversion channels store or redirect the flow of runoff waters, thus retaining suspended solids and nutrients.
Livestock exclusion	Limiting animal access to streams, streambanks, and lakes or ponds through the use of fencing or similar structures prevents grazing-related erosion and the direct input of nutrients from animal waste.
Streambank protection and grassed waterways	Grassed waterways in natural or constructed channels and the protection of streambanks with vegetation of structures reduce erosion and nutrient loss, especially during periods of high runoff.
Wetland development	Creation (using dams or modifying drainages) or restoration of wetlands offers the means to retain sediment and dissolved nutrients, while providing valuable habitat for wildlife.

Livestock waste, particularly when concentrated in feedlots or animal confinement areas, represents a significant source of nutrients and can lead to severe localized water quality impacts similar to those associated with point source discharges. Retaining and treating such material through the construct of manure handling and storage facilities can significantly reduce such impacts. Preventing or limiting livestock access to streams reduces streambank damage and subsequent erosion and the direct input of animal wastes (Figure 5). Constructed wetlands, settling basins, and retention devices

also reduce the delivery of materials to water resources. These and other commonly employed agricultural BMPs are listed and briefly discussed in Table 3.

IMPLEMENTATION: Watersheds are complex landscapes containing multiple potential sources of materials that can degrade water quality. Understanding linkages between land use, material export, and water quality response is key to designing and implementing an effective watershed management plan. This process will require the acquisition of information describing current conditions in the watershed, the degree of the water resource degradation or potential for impact, and the relative contribution of point and non-point sources to the observed degradation or anticipated impact. Table 4 lists analytical tools and models that are both easy to apply and obtain to assess water quality conditions and to design selected BMPs.

Figure 5. Unlimited animal access to streams increases bank erosion and introduces nutrients and organic matter

Effective BMP implementation also requires coordination of efforts between and among agencies, stakeholders, and residents, and the establishment of effective partnerships. Such partnerships represent a range of opportunities for the Corps of Engineers and its programs. These include federal grants (e.g., USEPA Non-point Source Program – Section 319, USEPA Clean Water Act grants – Section 106, USDA Wetland Reserve Program), federal cost-shared programs, regulatory programs (e.g., Section 404/10 permits, Special Area Management Plans, wetland mitigation plans), delegated authorities (e.g., planning assistance to states – Section 22, restoration of environmental quality – Section 1135, aquatic ecosystem restoration – Section 206), partnerships with non-governmental organizations, and partnerships with operating projects.

Table 4
Assessment and Analysis Tools for Designing, Implementing, and Evaluating Water Resource Management Activities

Application	Description
	Material Loading Estimation
FLUX	*Description:* Interactive software for computation of sediment and other water quality component loads from stream monitoring data using optimal statistical methods; evaluation of uncertainty in load estimates; outlier screening; optimization of sampling design; extensive graphical and diagnostic output. *Source: http://www.wes.army.mil/el/elmodels/index.html*
GISPLM	*Description:* Simulation of watershed runoff and phosphorus loads driven by GIS layers and other regional databases; daily rainfall//runoff simulation; formulation of water and nutrient balances in segmented watersheds consisting of networks of streams and reservoirs; optimal selection of urban and agricultural BMP's to meet watershed loading targets based upon BMP performance and cost. *Source: http://www.wwwalker.net/gisplm/*
	Lake Response Estimation
BATHTUB	*Description:* Interactive software for evaluating eutrophication and related water quality problems in lakes and reservoirs; formulation of steady-state water and mass balances in a one-dimensional branched network (applicable to individual reservoirs, spatially segmented reservoirs, and/or networks of reservoirs); reservoir inputs estimated from direct monitoring data and/or simplified watershed model driven by land use; application of empirical models to predict nutrient retention and concentrations of nutrients and related components (chlorophyll-a, transparency, organic nutrient fractions, hypolimnetic and metalimnetic oxygen depletion); initially calibrated to nationwide data sets from Corps reservoirs; tested against several independent reservoir and lake data sets; ranking of reservoir characteristics against nationwide data sets; several graphical and tabular output formats; simulation of any water quality component with first-order or second-order removal kinetics (e.g., sediment, conservative substances). *Source: http://www.wes.army.mil/el/elmodels/index.html*
CEQUAL-W2	*Description:* CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best-suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries. The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The water quality algorithms incorporate 21 constituents in addition to temperature including nutrient/ phytoplankton/dissolved oxygen (DO) interactions during anoxic conditions. Any combination of constituents can be simulated. The effects of salinity or total dissolved solids/salinity on density and thus hydrodynamics are included only if they are simulated in the water quality module. The water quality algorithm is modular, allowing constituents to be easily added as additional subroutines. *Source: http://www.wes.army.mil/el/elmodels/index.html*
	Management Planning and Design
P8 Urban Catchment Model	*Description:* Interactive software for simulating the generation and transport of particles (multiple size classes) and related contaminants in watersheds; continuous water-balance and mass-balance calculations in a user-defined network of subwatersheds and treament devices (detention ponds, swales, buffer strips, infiltration basins, etc.); simplified groundwater budget to simulate baseflow and total streamflow; continuous simulations driven by hourly rainfall and daily air temperature time series supplied in standard data exchange formats; estimation of outflow water quality and sediment accumulation rates in detention ponds and other treatment devices; pre-calibrated to particle characteristics and runoff water quality data derived from EPA's Nationwide Urban Runoff Program; developed initially for use in designing BMP's for existing or proposed urban developments; applicable to other watershed types with appropriate calibration data. *Source: http://www.wwwalker.net/p8/*
	(Continued)

Table 4 (Concluded)

Application	Description
Management Planning and Design (Continued)	
PONDNET	*Description:* Simulation of water and mass balances in networks of watersheds and detention ponds (or well-mixed lakes and reservoirs); driven by simplified annual-average or seasonal-average rainfall/runoff models; calibrated to predict phosphorus retention in wet detention ponds; applicable to sediment and other water quality components. *Source: http://www.nalms.org/*
PREWET	*Description:* A screening-level, analytical model was developed that can be rapidly applied with minimal input data for estimating the amount of water quality improvement provided by wetlands. Given basic characteristics about the wetland, pollutant removal efficiency (RE) can be computed for total suspended solids, total coliform bacteria, biochemical oxygen demand, total nitrogen, total phosphorus, and contaminants (e.g., organic chemicals and trace metals). The RE depends on the wetland detention time and the removal rate, K (day-1), for the constituent. The removal rates depend on a number of processes, such as microbial metabolism, adsorption, volatilization, denitrification, settling, etc., and ambient conditions, such as water temperature. The model was focused on the dominant long-term removal mechanisms, making use of literature values or mathematical formulations for those mechanisms when possible. A report documents the analytical model formulations for predicting pollutant RE provided by wetlands. These formulations have been programmed into an interactive, user-friendly, PC-based computer program, which is also described in the report. Predicted RE's for total suspended solids, total nitrogen, and total phosphorus are compared to observed RE's at the Cache River Wetland, Arkansas. *Source: http://www.wes.army.mil/el/elmodels/index.html*

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POINTS OF CONTACT: Information reported here is based on material presented at a workshop held 10-12 July 2001 in St. Paul, Minnesota, titled "Water Quality Management and Restoration Using Settling Basins, Wetlands and Other Watershed BMPs." The Wetlands Regulatory Assistance Program (WRAP) and the Water Operations Technical Support Program (WOTS) jointly sponsored the workshop. For additional information, contact the program manager of WRAP, Mr. Robert Lazor (601) 634-2935, *Bob.L.Lazor@erdc.usace.army.mil*. This technical note should be cited as follows:

> Kennedy, R. (2002). "Watershed BMPs for water quality management and restoration," *WRAP Technical Notes Collection* (ERDC TN-WRAP-02-04), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *http://www.wes.army.mil/el/wrap*